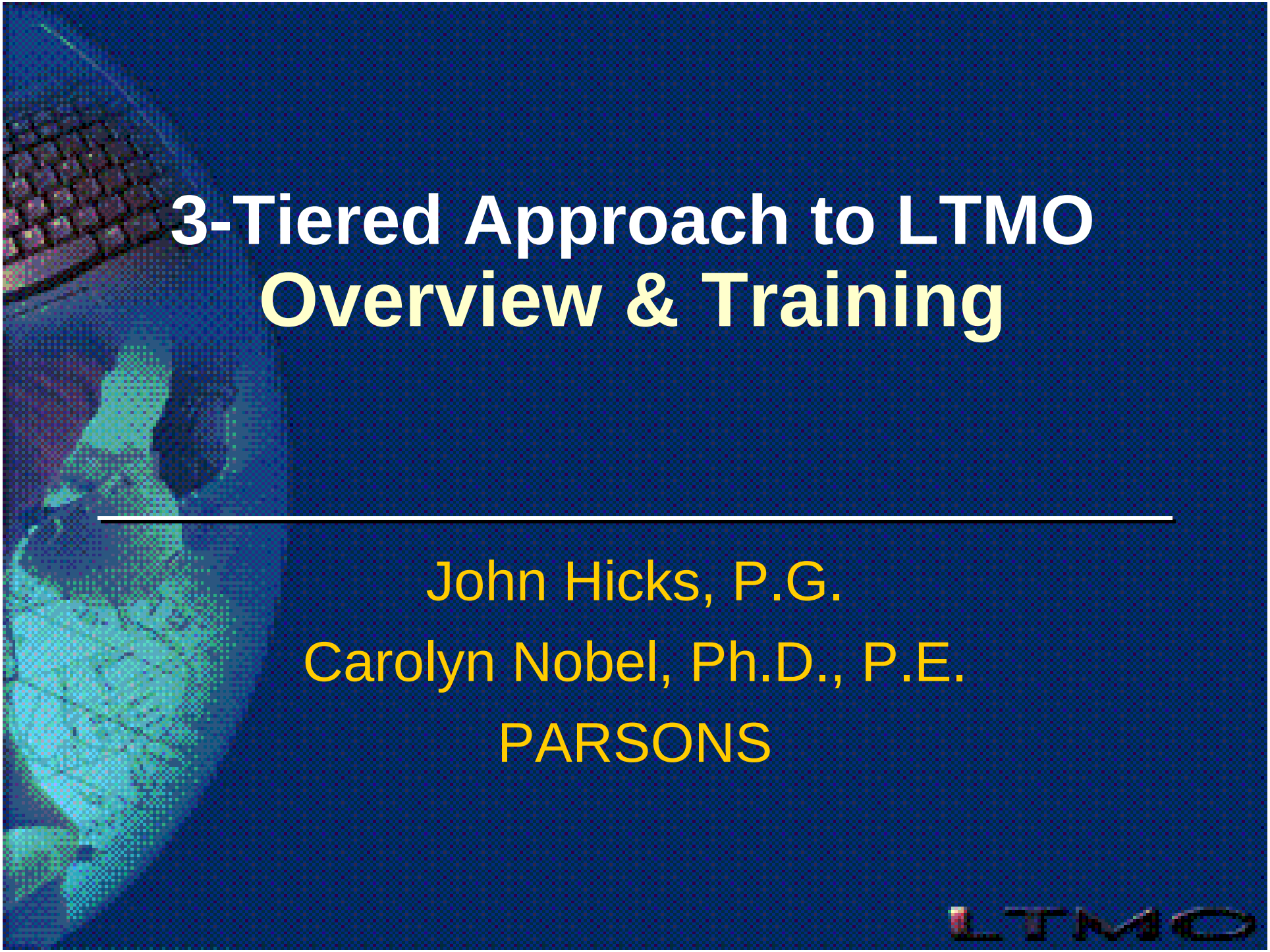


3-Tiered Approach to LTMO
Overview & Training

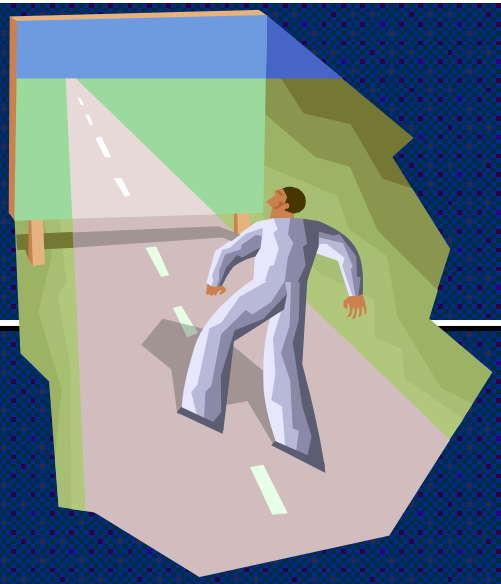
John Hicks, P.G.
Carolyn Nobel, Ph.D., P.E.
PARSONS

What's the Point?

Parsons'

3-Tiered LTMO Approach combines a qualitative evaluation with temporal and spatial statistics to evaluate the distribution and frequency of groundwater sampling.

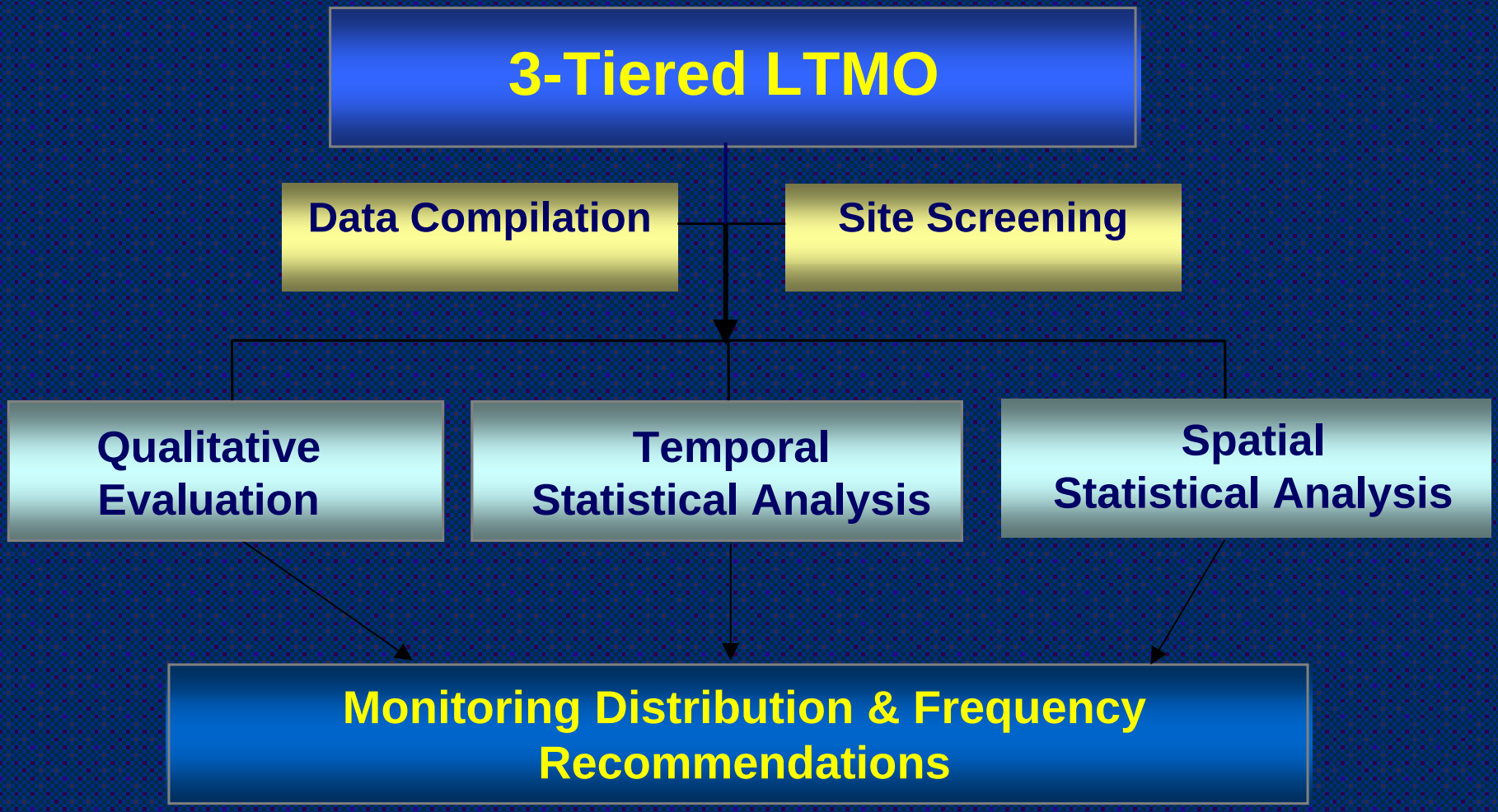
Outline



- 3-Tiered Approach Overview
- Data Requirements
- Site Screening
- Qualitative Evaluation
- Temporal Evaluation
- Spatial Evaluation
- Combined Evaluation
- Summary & Applications

Case Study Illustration

3-Tiered Approach at A Glance



3-Tiered Methodology

- Data Requirements
- Site Screening
- Qualitative Evaluation
- Temporal Evaluation
- Spatial Evaluation
- 3-Tiered Summary

Data Requirements

- Description of Current Monitoring Program & Sampling Rationale
- Historical Monitoring Results
- Well Information
- Plume Source, Nature, and Extent
- Hydrogeologic Conditions
- Site Features
- Cleanup Goals/Regulatory Limits
- Logistical/Policy Considerations

See Roadmap Table 2.2.1

Site Screening: Don't Even Go There?

- Adequate Data Availability & Format
- "Long Term Monitoring" Program & Adequately Characterized Site
- Greater than 10 Wells (preferably > 30) (spatial evaluation)
  - Same plume
  - Same aquifer/zone
  - Same timeframe
- At Least 4 Sampling Events Spaced Over 2 Years or More (temporal evaluation)
- Status Quo for Next Few Years
- Flexible Regulatory Environment

Site Screening Discussion: The Perfect Site

- Essential
- Wish List
- Deal Breakers

Case Study Introduction: Camp Stanley Storage Area, TX

- **Simplified version for case study**
  - **Only north-central area plume**
  - **Less than ½ of total site monitoring wells included**
  - **Simplified hydrogeology**
- U.S. Army Facility in operation since 1906 for the receipt, storage, and testing of munitions
- PCE solvent used as a degreasing agent
- Soil and groundwater impacted by PCE, TCE, and cis-1,2-DCE
- VOC plumes impacted the on-post and off-post water supply wells

Pre-Analysis
Data Preparation/Organization

- Analytical results over time
- Chemical of Concern (COC) Statistical Analysis
- Monitoring Program Summary
  - "Basecase"
- Basemap

COC Results Over Time

- Case study analytical results available for future reference
- Allows for quick viewing of specific well and chemical results without database manipulation
- User friendly!

CS-D PCE Results over Time

	A	B	C	D	E	F
1	Well ID	COC	Date	Qualifier	Result	MDL
3108	CS-D	PCE	12/4/91	ND	0.0	1
3109	CS-D	PCE	11/3/92	=	8.9	
3110	CS-D	PCE	5/26/94	=	82.0	
3111	CS-D	PCE	9/30/94	=	110.0	
3112	CS-D	PCE	12/19/94	=	120.0	
3113	CS-D	PCE	4/6/95	=	110.0	
3114	CS-D	PCE	6/14/95	=	64.0	
3115	CS-D	PCE	8/30/95	=	80.0	
3116	CS-D	PCE	12/12/95	=	110.0	
3117	CS-D	PCE	2/29/96	=	72.0	
3118	CS-D	PCE	12/13/00	=	63.6	0.04
3119	CS-D	PCE	3/20/01	=	63.5	0.04
3120	CS-D	PCE	6/13/01	=	110.0	1.6
3121	CS-D	PCE	9/13/01	=	120.0	1.1
3122	CS-D	PCE	3/14/02	=	100.0	0.36
3123	CS-D	PCE	6/18/02	=	110.0	0.2
3124	CS-D	PCE	9/9/02	=	170.0	0.67
3125	CS-D	PCE	12/12/02	=	180.0	0.5
3126	CS-D	PCE	3/20/03	=	180.0	0.33
3127	CS-D	PCE	6/19/03	=	200.0	0.67
3128	CS-D	PCE	9/18/03	=	220.0	0.5
3129	CS-D	PCE	12/10/03	=	230.0	1
3130	CS-D	PCE	3/11/04	=	160.0	0.5
3131	CS-D	PCE	6/16/04	=	180.0	0.4
3132	CS-D	PCE	6/16/04	=	170.0	0.5
3133	CS-D	PCE	9/8/04	=	170.0	0.5
3134	CS-D	PCE	9/8/04	=	160.0	0.67
3135	CS-D	PCE	12/7/04	=	140.0	1.7

See Table 1
For Case Study Data

COC Statistical Analysis

Primary COCs

COC	Total Samples[a/]	Range of Detects (µg/L)[b/]			Percentage of Detects	Percentage of Samples with MCL Exceedances	MCL (µg/L)	Number of Wells with Results	Number of Wells with Detections	Number of Wells with MCL Exceedances
PCE	600	0	-	230.0	37.7%	16.0%	5	41	24	6
TCE	602	0	-	300.0	29.2%	15.9%	5	41	17	6
DCE12C	572	0	-	290.0	26.0%	8.9%	70	41	12	3
PB	277	0	-	250.0	59.6%	8.7%	15	32	27	9
BDCME	587	0	-	5.9	1.9%	1.9%	0	41	4	4
MTLNCL	586	0	-	9.6	25.4%	1.2%	5	41	36	6
CD	275	0	-	15.4	22.2%	1.1%	5	32	23	3
TBME	349	0	-	3.4	0.9%	0.9%	0	41	3	3
NI	276	0	-	216.0	47.5%	0.7%	100	32	27	2
BA	274	0	-	300.0	95.6%	0%	2000	32	32	
AS	279	0	-	30.0	57.7%	0%	50	32	29	
CU	280	0	-	180.0	55.0%	0%	1300	32	27	
CR	277	0	-	39.0	37.9%	0%	100	32	27	
BZME	390	0	-	40.4	28.2%	0%	1000	41	31	
TCLME	599	0	-	53.5	16.9%	0%	80	41	10	
DCE12T	609	0	-	12.0	14.9%	0%	100	41	9	
HG	276	0	-	1.3	11.6%	0%	2	32	17	
DCE11	584	0	-	1.0	4.3%	0%	70	41	11	
VC	548	0	-	1.3	4.2%	0%	2	41	11	
DBCME	587	0	-	4.5	1.4%	0%	60	41	4	

See Table 2 for Case Study Data

- Data summary snapshot
- Use to identify/ confirm primary COCs
- Analyze for all wells or by zone

Monitoring Program Summary

- "Basecase"
- Includes:
  - Wells to include in LTMO
  - Hydrogeologic Zone
  - Current Sampling Frequency
  - Sampling Date Range
  - Relative Plume Location

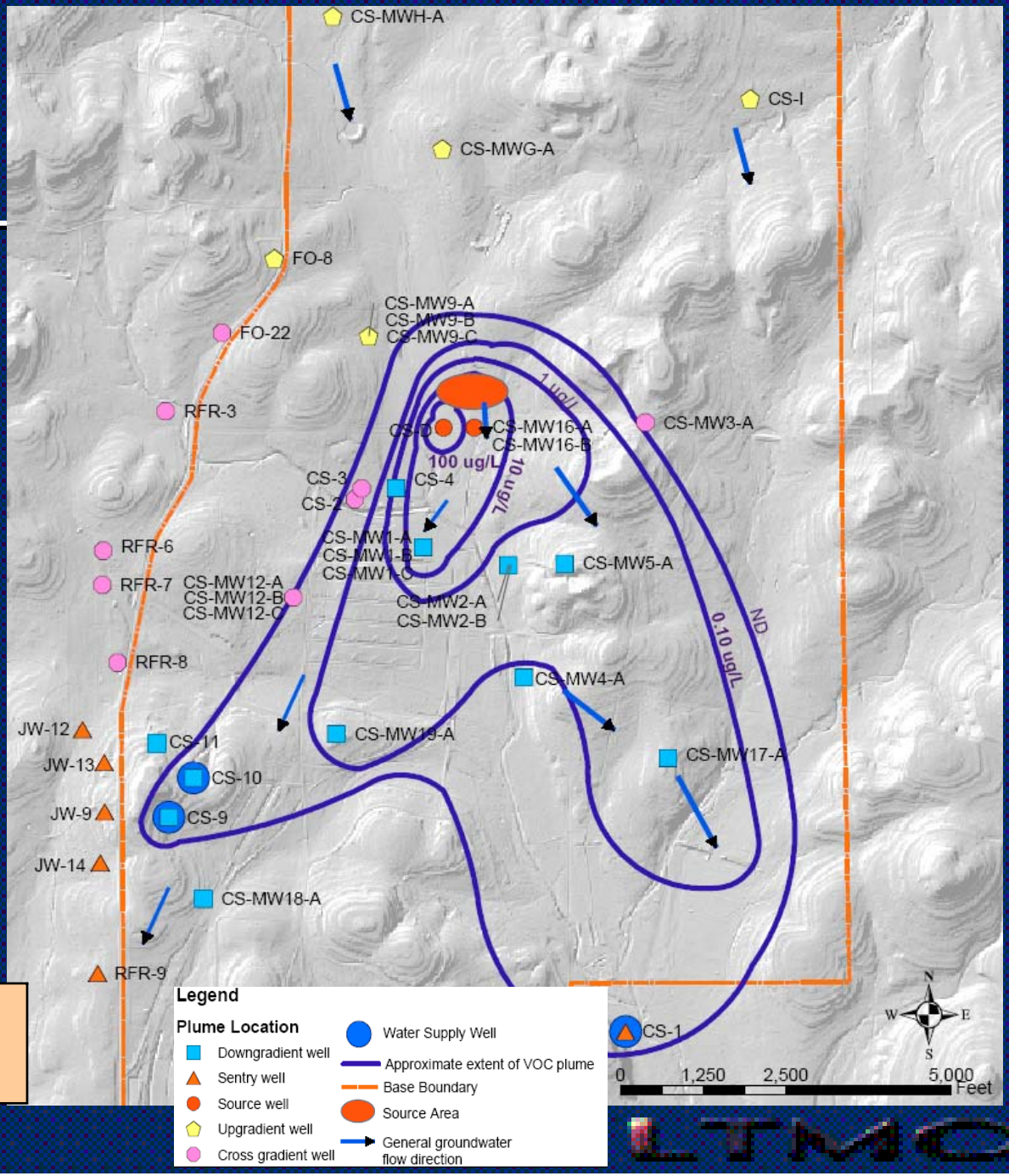
Well ID	Vertical Zone	Sampling Frequency	First Sampling Event	Most Recent Data	Plume Position
On Post Monitoring Wells					
CS-1	A	Quarterly	8/9/91	12/2/04	Sentry
CS-10	A	Quarterly	8/9/91	12/3/04	Downgradient
CS-11	A	Quarterly	8/9/91	12/3/04	Downgradient
CS-2	A	Quarterly	11/3/92	12/7/04	Cross gradient
CS-3	A	Quarterly	11/4/92	12/16/99	Cross gradient
CS-4	A	Quarterly	12/4/91	12/7/04	Downgradient
CS-9	A	Quarterly	8/9/91	12/3/04	Downgradient
CS-D	A	Quarterly	12/4/91	12/7/04	Source
CS-I	A	Quarterly	11/4/92	11/29/04	Up gradient
CS-MW12-C	C	Quarterly	12/16/02	12/7/04	Downgradient
CS-MW12-B	B	Quarterly	12/16/02	12/7/04	Downgradient
CS-MW12-A	A	Quarterly	12/16/02	12/7/04	Cross gradient
CS-MW16-B	B	Quarterly	9/16/03	12/9/04	Downgradient
CS-MW16-A	A	Quarterly	9/30/94	12/3/04	Source
CS-MW17-A	A	Quarterly	9/12/02	11/29/04	Downgradient
CS-MW18-A	A	Quarterly	9/12/02	12/7/04	Downgradient
CS-MW19-A	A	Quarterly	9/12/02	12/7/04	Downgradient
CS-MW1-C	C	Quarterly	3/25/03	11/30/04	Downgradient
CS-MW1-B	B	Quarterly	3/25/03	11/30/04	Downgradient
CS-MW1-A	A	Quarterly	9/8/99	11/30/04	Downgradient
CS-MW2-B	B	Quarterly	6/17/03	12/1/04	Downgradient
CS-MW2-A	A	Quarterly	9/9/99	12/1/04	Downgradient
CS-MW3-A	A	Quarterly	6/14/01	11/29/04	Cross gradient
CS-MW4-A	A	Quarterly	6/14/01	12/1/04	Downgradient
CS-MW5-A	A	Quarterly	6/14/01	12/3/04	Downgradient
CS-MW9-C	C	Quarterly	6/14/01	11/29/04	Downgradient
CS-MW9-B	B	Quarterly	6/14/01	11/29/04	Downgradient
CS-MW9-A	A	Quarterly	6/14/01	11/29/04	Up gradient
CS-MWG-A	A	Quarterly	11/3/92	11/29/04	Up gradient
CS-MWH-A	A	Quarterly	11/4/92	11/29/04	Up gradient
Off Post Monitoring					
FO-22	A	Annually	9/18/01	12/16/04	Cross gradient
FO-8	A	Annually	3/19/02	3/4/04	Up gradient

See Table 3 & Handout For Case Study Data

Basemap

- Spatial representation of monitoring network
- Well type/zone delineation
- General groundwater flow direction & plume location

See Figure 1 & Handout For Case Study Basemap



Site Conceptual Model

- Aquifer Material: **sand and silty sand**
- Groundwater Flow Direction: **SW to SE**
- Groundwater Flow Velocity: **avg 0.5 ft/day**
- Potential Receptor Locations: **mixed ranching and residential S and W of plume (off-post domestic and stock wells)**
- Unique Site Conditions: **source area SVE, water supply wells, bedrock high channels groundwater flow, adjacent property owners sensitive to off-post migration**

Qualitative Evaluation Methodology

- **DATA:**
  - Site characterization
  - Monitoring results
  - Monitoring Network DQOs, etc.
- **INFORMATION:**
  - Value of each well in big picture context
- **SOLUTION:**
  - Recommend:
    - Well retention or removal
    - Optimal sampling frequency
  - Provide Rationale

Requires Experienced Environmental Scientist Familiar With Site

Qualitative Well Spatial Distribution Decision Logic

Reasons for Retaining or Adding a Well in a Monitoring Network	*Reasons for Removing a Well From a Monitoring Network*
Well is needed to further characterize the site or monitor changes in contaminant concentrations through time	Well provides spatially redundant information with a neighboring well (e.g., same constituents, and/or short distance between wells
Well is important for defining the lateral or vertical extent of contaminants	Well has been dry for more than two years and there is no expectation for the water levels to recovery in the foreseeable future.
Well is needed to monitor water quality at a compliance point or receptor exposure point (i.e., sentinel well for municipal wells)	Contaminant concentrations are consistently below laboratory detection limits or cleanup goals
Well is important for defining background water quality	

Qualitative Monitoring Frequency Decision Logic

Reasons for Increasing Sampling Frequency	*Reasons for Decreasing Sampling Frequency*
Groundwater velocity is high	Groundwater velocity is low
Change in concentration would significantly alter a decision or course of action	Change in concentration would not significantly alter a decision or course of action
Well is close to source area or operating remedy	Well is farther from source area or operating remedy
Cannot predict if concentrations will change significantly over time or there have been recent irregular or contradictory data for which there is no ready explanation	Concentrations are not expected to change significantly over time, or contaminant levels have been below cleanup objectives for some period of time

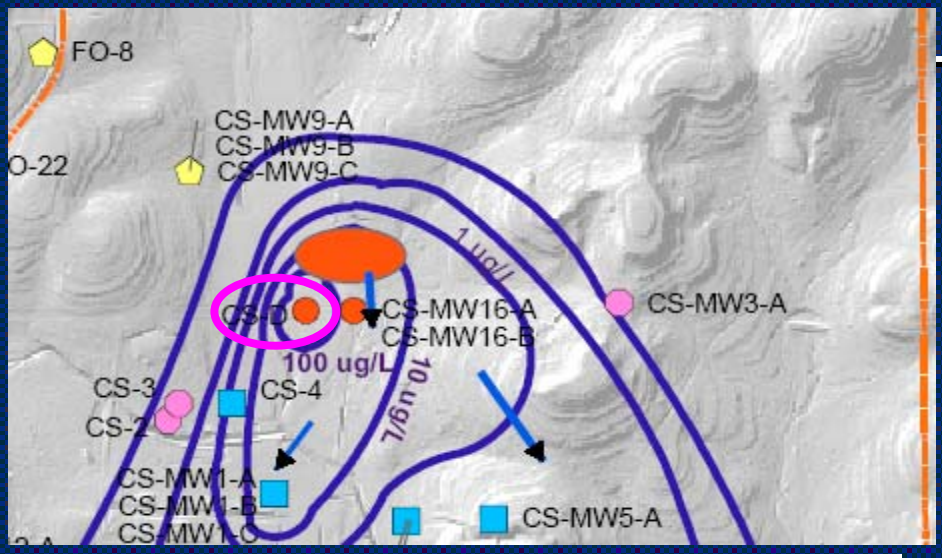
Case Study Application: Qualitative Evaluation

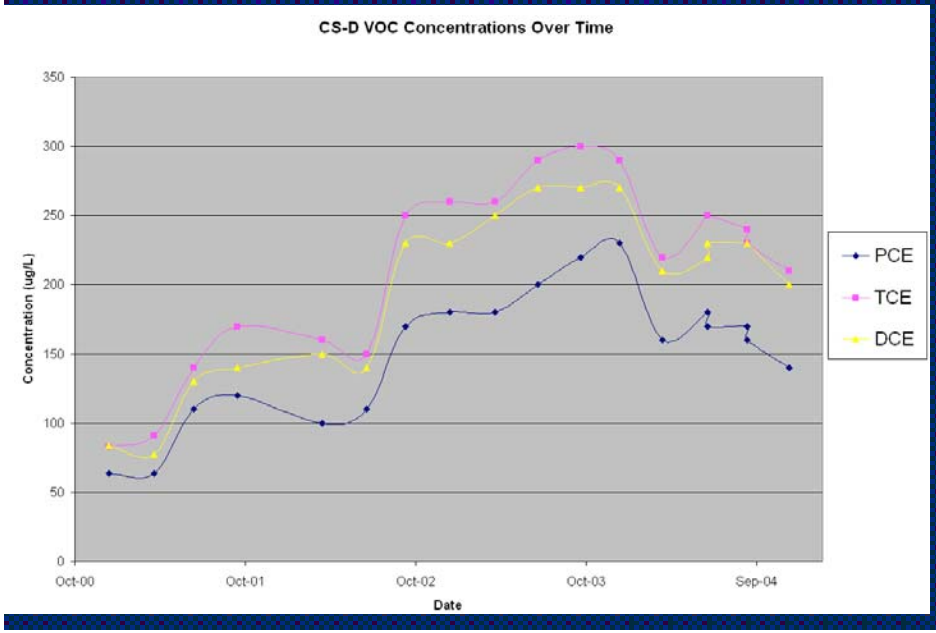
Well ID	Current Sampling Frequency	Qualitative Analysis			
		Remove	Retain	Monitoring Frequency Recommendation	Rationale
On Post Monitoring Wells					
CS-1	Quarterly		X	Semi-annual	On-post drinking water supply; no nearby upgradient wells for early warning
CS-10	Quarterly		X	Semi-annual	On-post drinking water supply; no nearby upgradient wells for early warning
CS-11	Quarterly		X	Annual	Serves as early warning of potential off-post migration
CS-2	Quarterly		X	Biennial	Cross-gradient well defines plume boundary over time
CS-3	Quarterly	X		Remove	Spatially redundant with CS-2, not recently sampled
CS-4	Quarterly	X		Remove	Spatially redundant with CS-2
CS-9	Quarterly		X	Semi-annual	On-post drinking water supply; no nearby upgradient wells for early warning
CS-D	Quarterly				
CS-I	Quarterly	X		Remove	MWG and MW9 provide sufficient upgradient data
CS-MW12-C	Quarterly		X	Biennial	Vertical sentry well, historically non-detect
CS-MW12-B	Quarterly		X	Biennial	Vertical sentry well, historically non-detect
CS-MW12-A	Quarterly				
CS-MW16-B	Quarterly		X	Semi-annual	Monitors vertical migration of contaminants beneath source; only 1.25 yrs of LTM
CS-MW16-A	Quarterly		X	Semi-annual	Monitors effectiveness of source area remediation
CS-MW17-A	Quarterly		X	Annual	Along inferred plume flowpath; good indicator of plume st
CS-MW18-A	Quarterly		X	Annual	Serves as early warning of potential off-post migration
CS-MW19-A	Quarterly		X	Annual	Along inferred plume flowpath; good indicator of plume st
CS-MW1-C	Quarterly		X	Biennial	Vertical sentry well, historically < PQL
CS-MW1-B	Quarterly		X	Biennial	Vertical sentry well, historically non-detect
CS-MW1-A	Quarterly				
CS-MW2-B	Quarterly		X	Biennial	Vertical sentry well, historically non-detect
CS-MW2-A	Quarterly		X	Biennial	Below MCLs for last 12 events
CS-MW3-A	Quarterly		X	Biennial	Cross-gradient well defines plume boundary over time
CS-MW4-A	Quarterly	X		Remove	COCs consistently < MCLs; not on plume flowpath
CS-MW5-A	Quarterly		X	Biennial	COCs consistently < MCLs; very little temporal variation
CS-MW9-C	Quarterly		X	Biennial	Vertical sentry well, historically non-detect
CS-MW9-B	Quarterly		X	Biennial	Vertical sentry well, historically non-detect or < PQL
CS-MW9-A	Quarterly		X	Biennial	Monitors upgradient groundwater quality
CS-MWG-A	Quarterly		X	Biennial	Monitors upgradient groundwater quality
CS-MWH-A	Quarterly				
Off Post Monitoring Wells					
FO-22	Annually	X		Remove	Hydraulically upgradient to cross-gradient; historically non-detect
FO-8	Annually	X		Remove	MWG and MW9 provide sufficient upgradient data
JW-12	Annually		X	Annual	Downgradient property boundary sentry well
JW-13	Annually		X	Annual	Downgradient property boundary sentry well
JW-14	Quarterly		X	Annual	Downgradient property boundary sentry well
JW-9	Quarterly		X	Annual	Downgradient property boundary sentry well
RFR-3	Quarterly	X		Remove	Resume LTM if CS-2 indicates significant westerly migration; otherwise of no value
RFR-6					ntry well
RFR-7					ntry well
RFR-8					ntry well
RFR-9					ntry well; other wells provide early warning

Recommend removal/retention and monitoring frequency for case study wells based on qualitative factors. List rationale.

See Table 4 and Handout for Qualitative Evaluation Template

CS-D Illustration

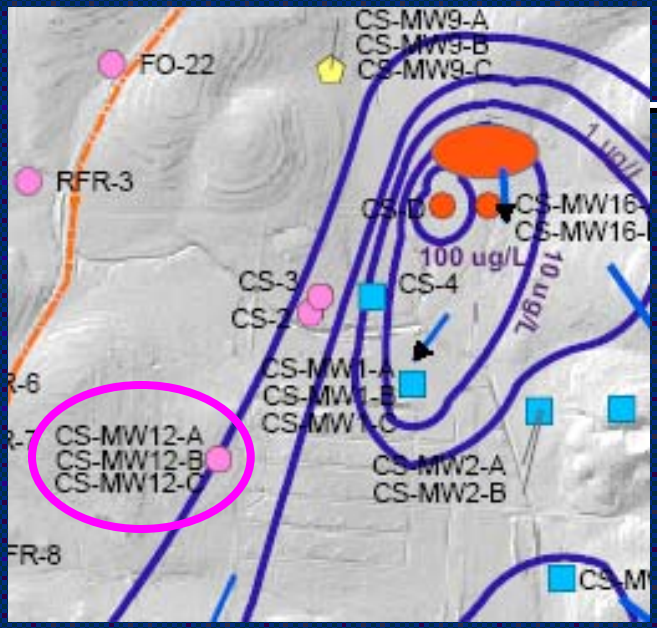


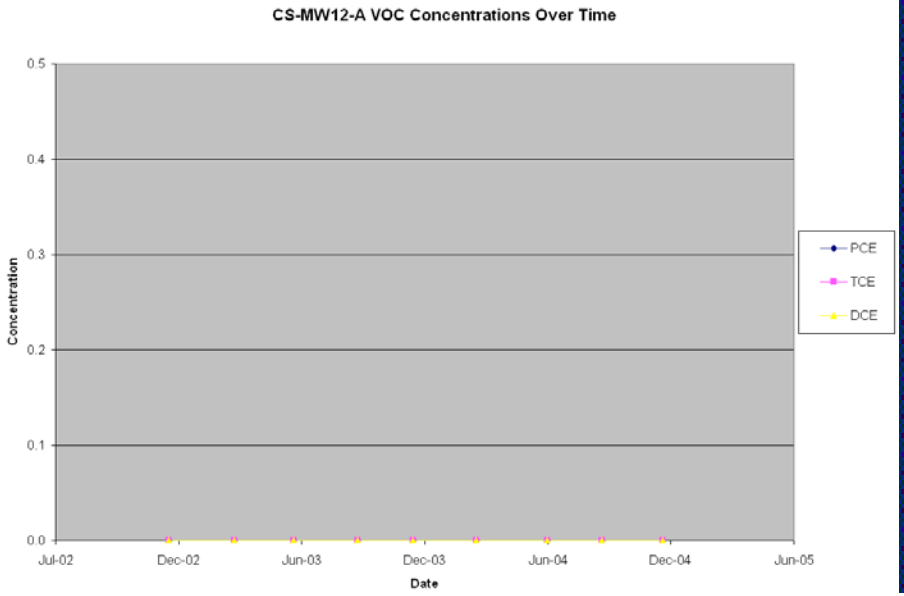


- Source area well
- High VOC concentrations >> MCL
- Monitors effectiveness of source area remediation
- **RETAIN**
- **Semi-Annual frequency**

See Figure 3 & Handout for Case Study Wells VOC Results

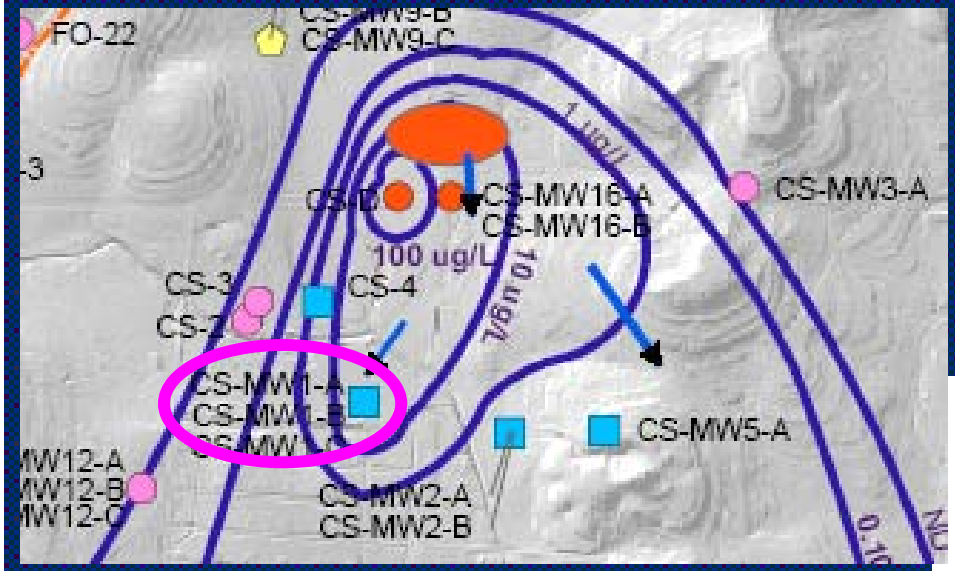
CS-MW12-A Illustration

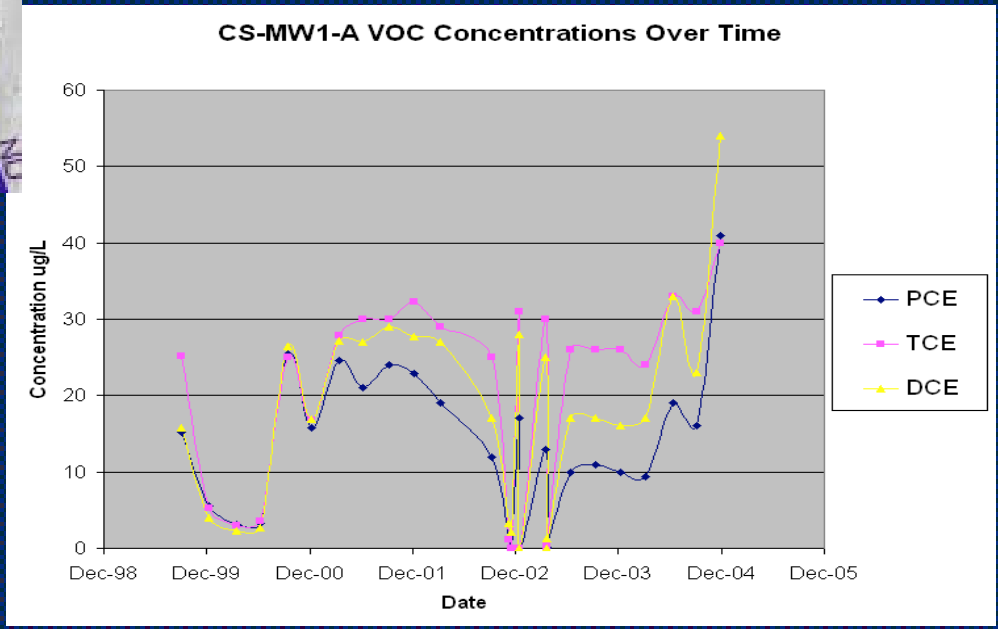




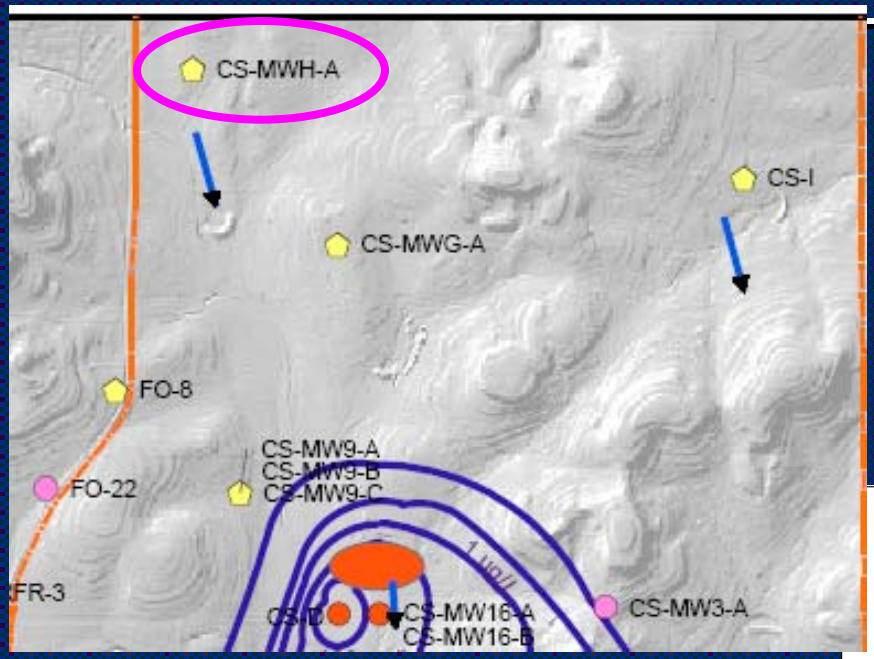
- Cross gradient well
- COCs historically ND
- Defines plume boundary over time
- RETAIN
- Biennial frequency

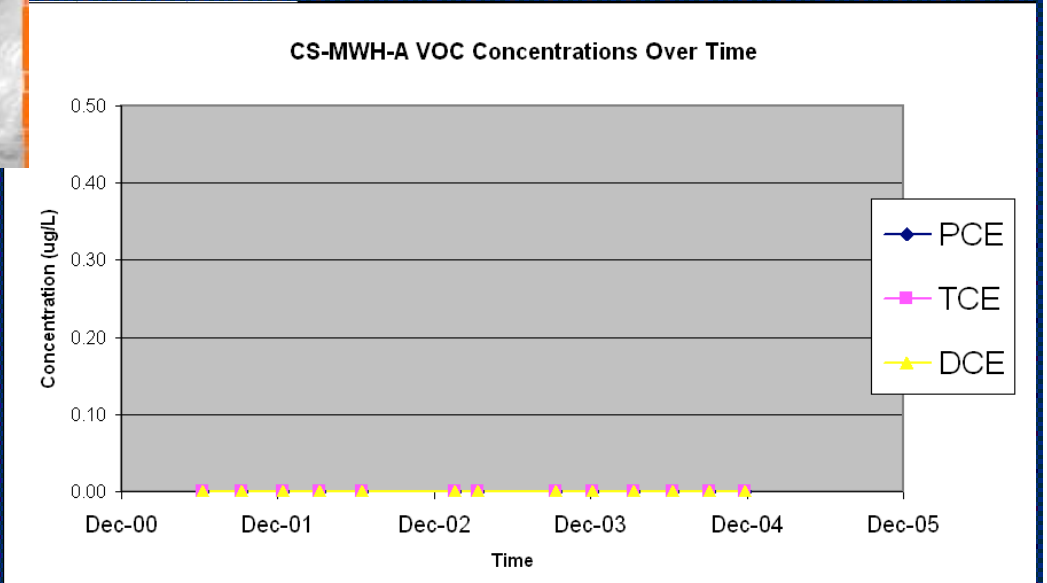
CS-MW-1A Illustration





CS-MWH-A Illustration





Temporal Statistical Evaluation Methodology

- DATA:
  - >4 sampling results over time
  - Well/plume location & GW flow direction
  - Chemical concentration
- INFORMATION:
  - Mann-Kendall Trend analysis
  - Automated process
- SOLUTION:
  - Recommend retention or removal/reduction based on decision rationale

Mann-Kendall Benefits, Limitations & Issues

- Nonparametric analysis (no data distribution required)
- Consistent sampling not required
- Uses relative magnitudes– less sensitive to outliers
- Allows use of NDs
- Potential “spurious trends” with all ND or Trace values
- >4 values required for robust trends

Mann Kendall Trend Analysis Example Analysis

Well ID	Date	COC	Qualifier	Result	81	25	170	170	75	39
CS-MW16-LGR	9/30/1994	PCE	=	81.0						
CS-MW16-LGR	12/19/1994	PCE	=	25.0	-1					
CS-MW16-LGR	4/6/1995	PCE	=	170.0	1	1				
CS-MW16-LGR	4/7/1995	PCE	=	170.0	1	1	0			
CS-MW16-LGR	5/26/1995	PCE	=	75.0	-1	1	-1	-1		
CS-MW16-LGR	6/14/1995	PCE	=	39.0	-1	1	-1	-1	-1	
CS-MW16-LGR	8/30/1995	PCE	=	78.0	-1	1	-1	-1	1	1
CS-MW16-LGR	12/13/1995	PCE	=	64.0	-1	1	-1	-1	-1	1
CS-MW16-LGR	2/29/1996	PCE	=	158.0	1	1	-1	-1	1	1
CS-MW16-LGR	9/14/1999	PCE	=	159.0	1	1	-1	-1	1	1
CS-MW16-LGR	12/14/1999	PCE	=	160.8	1	1	-1	-1	1	1
CS-MW16-LGR	4/27/2000	PCE	=	95.4	1	1	-1	-1	1	1
CS-MW16-LGR	6/13/2000	PCE	=	129.0	1	1	-1	-1	1	1
CS-MW16-LGR	9/15/2000	PCE	=	167.2	1	1	-1	-1	1	1
CS-MW16-LGR	12/13/2000	PCE	=	85.7	1	1	-1	-1	1	1
CS-MW16-LGR	3/20/2001	PCE	=	125.7	1	1	-1	-1	1	1
CS-MW16-LGR	6/13/2001	PCE	=	75.0	-1	1	-1	-1	0	1
CS-MW16-LGR	9/13/2001	PCE	=	140.0	1	1	-1	-1	1	1
CS-MW16-LGR	12/14/2001	PCE	=	148.4	1	1	-1	-1	1	1
CS-MW16-LGR	3/14/2002	PCE	=	28.0	-1	1	-1	-1	-1	-1
CS-MW16-LGR	6/18/2002	PCE	=	95.0	1	1	-1	-1	1	1
CS-MW16-LGR	9/9/2002	PCE	=	54.0	-1	1	-1	-1	-1	1
CS-MW16-LGR	12/12/2002	PCE	=	93.0	1	1	-1	-1	1	1
CS-MW16-LGR	3/21/2003	PCE	=	90.0	1	1	-1	-1	1	1
CS-MW16-LGR	6/19/2003	PCE	=	18.0	-1	-1	-1	-1	-1	-1
CS-MW16-LGR	9/18/2003	PCE	=	12.0	-1	-1	-1	-1	-1	-1
CS-MW16-LGR	12/10/2003	PCE	=	14.0	-1	-1	-1	-1	-1	-1
CS-MW16-LGR	3/11/2004	PCE	=	12.0	-1	-1	-1	-1	-1	-1
CS-MW16-LGR	6/16/2004	PCE	=	48.0	-1	1	-1	-1	-1	1
CS-MW16-LGR	9/8/2004	PCE	=	64.0	-1	1	-1	-1	-1	1
CS-MW16-LGR	12/3/2004	PCE	=	29.0	-1	1	-1	-1	-1	-1
				Total Sum	-157					
				ND	0	TR	0	N	31	

④ TREND, ND or PQL? TREND

Z	-2.65
Confidence	99.60%
Result	Decreasing

⑤ ⑥

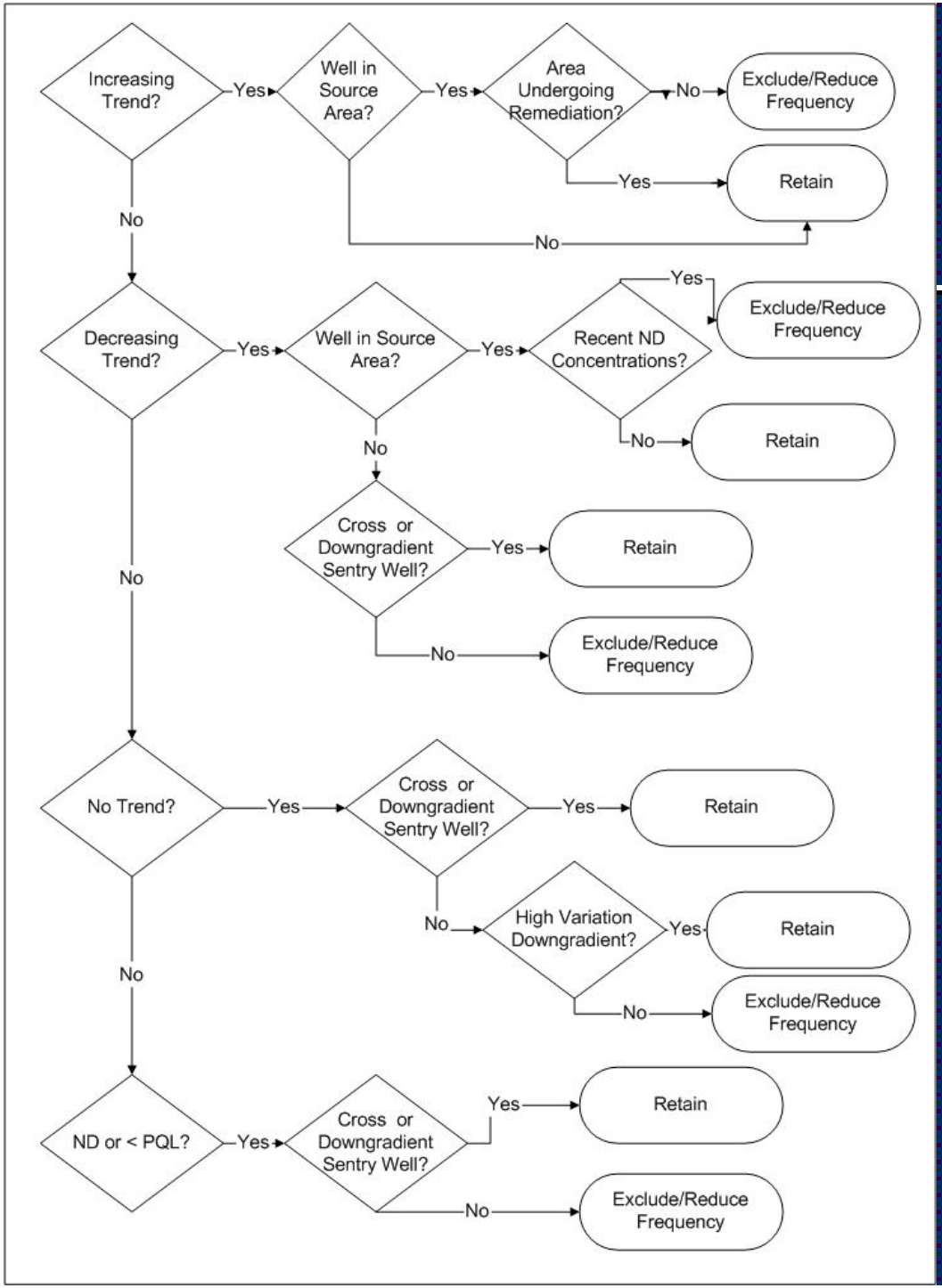
① ② ③

- Compare values (e.g., 25<81→-1)
- Sum all compared values
- Count # of values, NDs, & TRs in data set
- Determine if Trend, ND (All = ND) or PQL (All ND or TR)
- Calculate Z value and corresponding normal distribution confidence level
- Determine trend based on defined confidence limit (e.g., 95%)

See Table 5 for Mann Kendall Example Worksheet

3-Tiered Trend Analysis Options

Mann-Kendall Result	No Trend	= No statistically significant temporal trend in concentrations.
	Increasing	= Statistically significant increasing trend in concentrations.
	Decreasing	= Statistically significant decreasing trend in concentrations.
3-Tiered Classifications	ND	= Constituent has not been detected during history of monitoring at indicated well.
	PQL	= Concentrations consistently not detected or trace (below practical quantitation limit)



Temporal Trend Decision Rationale Flowchart

See Figure 3 & Handout For Temporal Trend Rationale Flowchart

Case Study Application: Temporal Evaluation

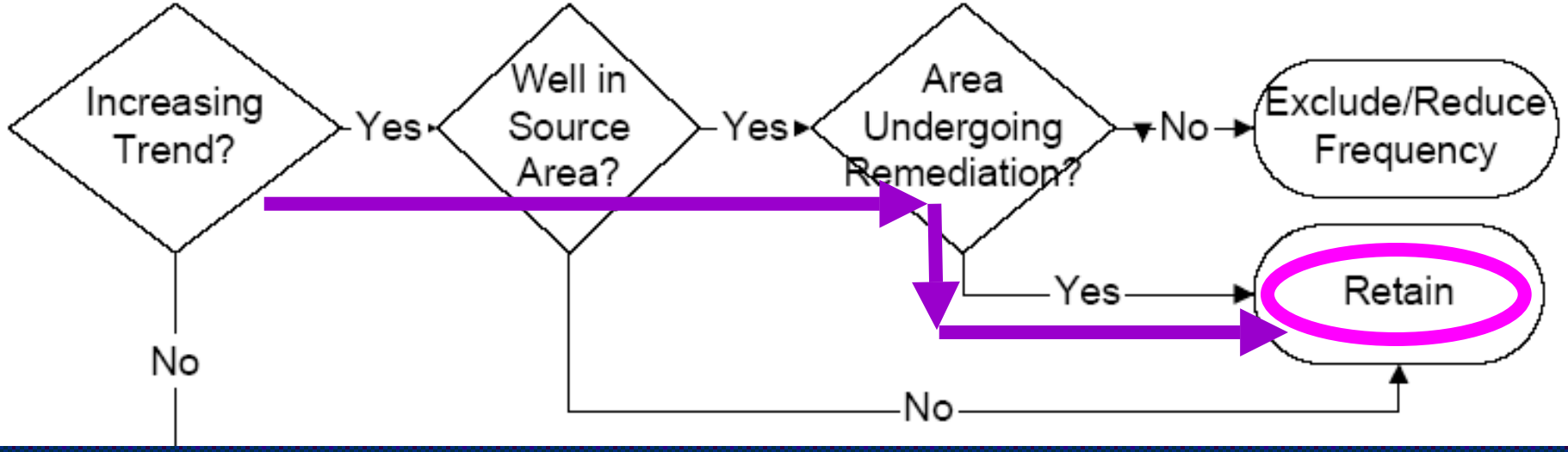
Well ID	Realitive Plume Location	PCE	TCE	cis-1,2-DCE	Remove/ Reduce	Retain	Rationale
On Post Monitoring Wells							
CS-1	Sentry	PQL	No Trend	ND		X	Downgradient sentry well; one low detection of TCE in 2000
CS-10	Downgradient	PQL	ND	ND	X		Downgradient; COCs PQL or ND
CS-11	Downgradient	PQL	PQL	PQL	X		Downgradient; COCs PQL
CS-2	Cross gradient	No Trend	PQL	ND	X		Cross gradient; only trace PCE since 1999
CS-3	Cross gradient	No Trend	ND	ND	X		Cross gradient; well not measured since 1999 (trace PCE concentrations)
CS-4	Downgradient	No Trend	Increasing	Increasing		X	Increasing TCE and DCE downgradient of source well
CS-9	Downgradient	PQL	ND	ND	X		Downgradient; lead consistently <5ug/L; all other ND or PQL.
CS-D	Source	Increasing	Increasing	Increasing		X	
CS-I	Up gradient	PQL	PQL	ND	X		Up gradient well; COCs PQL or ND
CS-MW12-C	Downgradient	ND	ND	ND	X		Downgradient (lower aquifer) well historically ND
CS-MW12-B	Downgradient	ND	ND	ND	X		Downgradient (lower aquifer) well historically ND
CS-MW12-A	Cross gradient	ND	ND	ND	X		
CS-MW16-B	Downgradient	No Trend	No Trend	No Trend		X	Variable PCE, TCE, and DCE >
CS-MW16-A	Source	Decreasing	Decreasing	Decreasing		X	Decreasing TCE, PCE, and DCE
CS-MW17-A	Downgradient	PQL	PQL	ND	X		Downgradient ND or PQL
CS-MW18-A	Downgradient	PQL	PQL	ND	X		Downgradient; COCs historicall
CS-MW19-A	Downgradient	PQL	ND	ND	X		Downgradient; COCs historicall
CS-MW1-C	Downgradient	PQL	PQL	Decreasing	X		Downgradient (lower aquifer) w
CS-MW1-B	Downgradient	ND	ND	ND	X		Downgradient (lower aquifer) w
CS-MW1-A	Downgradient	No Trend	Increasing	No Trend		X	
CS-MW2-B	Downgradient	ND	ND	ND	X		Downgradient (lower aquifer) w
CS-MW2-A	Downgradient	Decreasing	Decreasing	Decreasing	X		Decreasing trends in downgradie
CS-MW3-A	Cross gradient	PQL	PQL	ND	X		Cross gradient;COCs ND or PQ
CS-MW4-A	Downgradient	PQL	PQL	PQL	X		Downgradient; COCs PQL
CS-MW5-A	Downgradient	No Trend	No Trend	No Trend	X		Stable COCs downgradient
CS-MW9-C	Downgradient	ND	ND	ND	X		Downgradient (lower aquifer) well; COCs ND or PQL
CS-MW9-B	Downgradient	ND	ND	PQL	X		Downgradient (lower aquifer) well; COCs ND or PQL
CS-MW9-A	Up gradient	PQL	PQL	ND	X		Up gradient; COCs historically ND or PQL
CS-MWG-A	Up gradient	ND	ND	ND	X		Upgradient well; COCs ND
CS-MWH-A	Up gradient	ND	ND	ND	X		
Off Post Monitoring Wells							
FO-22	Cross gradient	ND	ND	ND	X		Cross gradient; COCs historically ND
FO-8	Up gradient	<4Meas	<4Meas	<4Meas	Not Analyzed		No recommendation due to limited data over time.
JW-12	Sentry	<4Meas	<4Meas	<4Meas	Not Analyzed		No recommendation due to limit
JW-13	Sentry	ND	ND	ND		X	Downgradient sentry well; COC
JW-14	Sentry	PQL	ND	ND		X	Downgradient sentry well; COC
JW-9	Sentry	PQL	ND	PQL		X	Downgradient sentry well; COC
RFR-3	Cross gradient	PQL	ND	ND	X		Cross gradient; COCs historicall
RFR-6	Cross gradient	ND	ND	ND	X		Cross gradient; COCs historicall
RFR-7	Cross gradient	ND	ND	ND	X		Cross gradient; COCs historicall
RFR-8	Cross gradient	ND	ND	ND	X		Cross gradient; COCs historicall
RFR-9	Sentry	ND	ND	ND		X	Downgradient sentry well; COCs historically ND

Recommend reduce/remove or retain for case study wells based on trend results and decision flowchart
List rationale.

See Table 6 & Handout for Temporal Trend Results & Evaluation Template

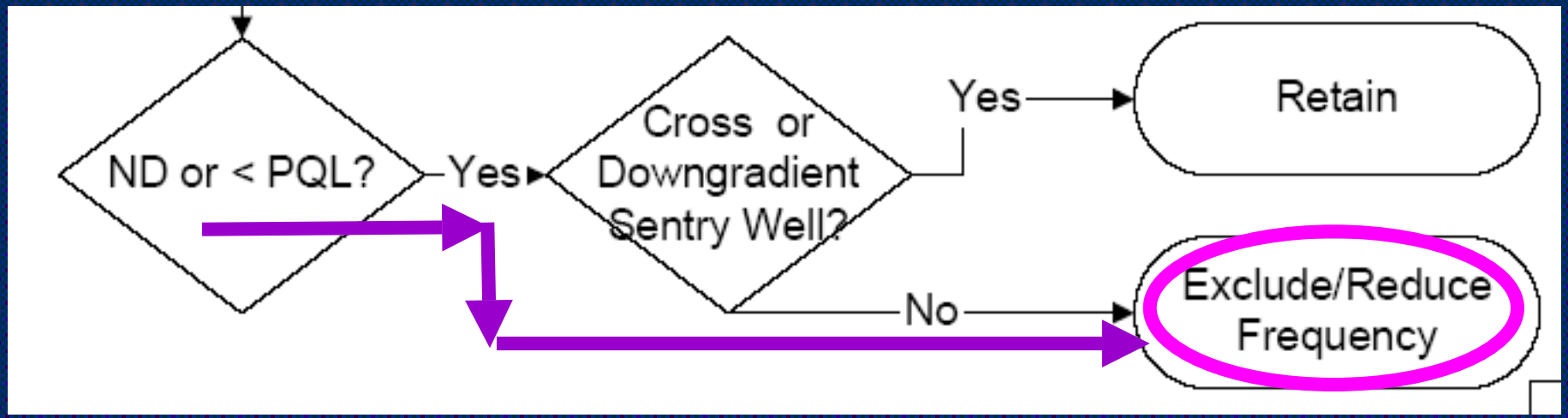
CS-D → RETAIN

Well ID	Realitive Plume Location	PCE	TCE	cis-1,2-DCE
CS-D	Source	Increasing	Increasing	Increasing



CS-MW12-A→ EXCLUDE/REDUCE FREQUENCY

Well ID	Realitive Plume Location	PCE	TCE	cis-1,2-DCE
CS-MW12-A	Cross gradient	ND	ND	ND



CS-MW1-A

Well ID	Realitive Plume Location	PCE	TCE	cis-1,2-DCE
CS-MW1-A	Downgradient	No Trend	Increasing	No Trend

CS-MWH-A

Well ID	Realitive Plume Location	PCE	TCE	cis-1,2-DCE
CS-MWH-A	Up gradient	ND	ND	ND

Spatial Statistics Evaluation Methodology

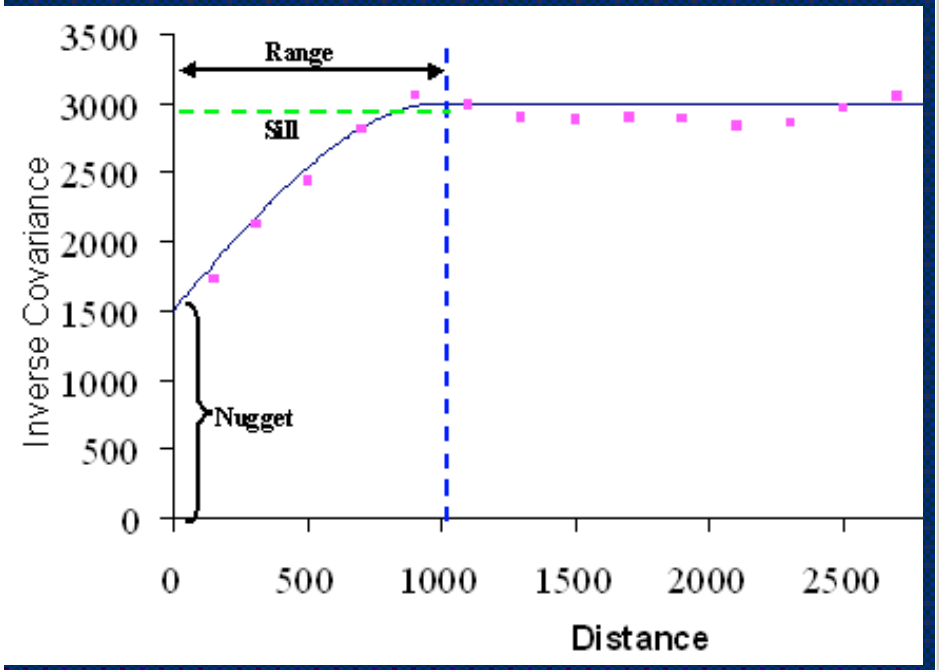
- DATA
  - Spatial "Snapshot" of Plume
    - Most recent chemical concentrations
    - Indicator chemical
    - Wells in same zone
- INFORMATION:
  - Geostatistical (Kriging) Evaluation
    - Develop spatial model (semivariogram)
    - Calculate Kriging predicted standard error metric for each well
  - Conducted Using ArcGIS Geostatistical Analyst Extension or other geostatistical analysis program
- SOLUTION:
  - Recommend removal or retention based on relative spatial value of information from each well

Requires Experience with Geostatistics & Semivariogram Development

Spatial Statistics Well Selection & Data Preparation

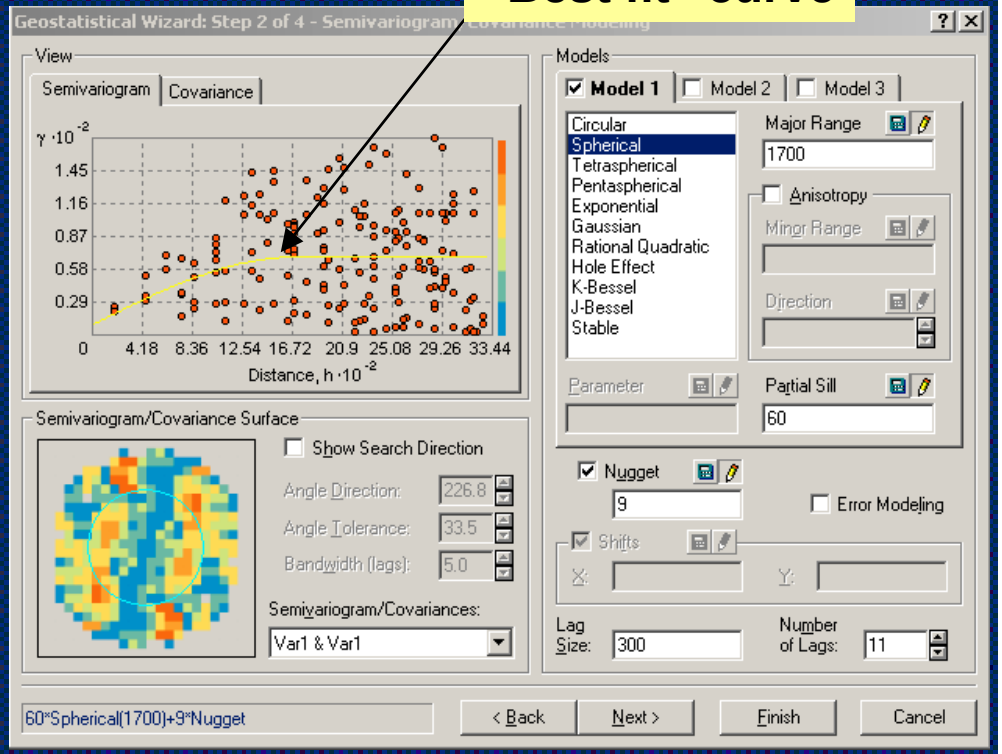
- Select spatial evaluation well set
  - Same zone
  - Same time
- Define “Indicator” Chemical
  - COC with highest concentrations/spatial extent
  - Sum or weighted sum of several COCs
  - Multiple COC Analyses
- Develop “Best-Fit” Semivariogram

Semivariogram Model Development



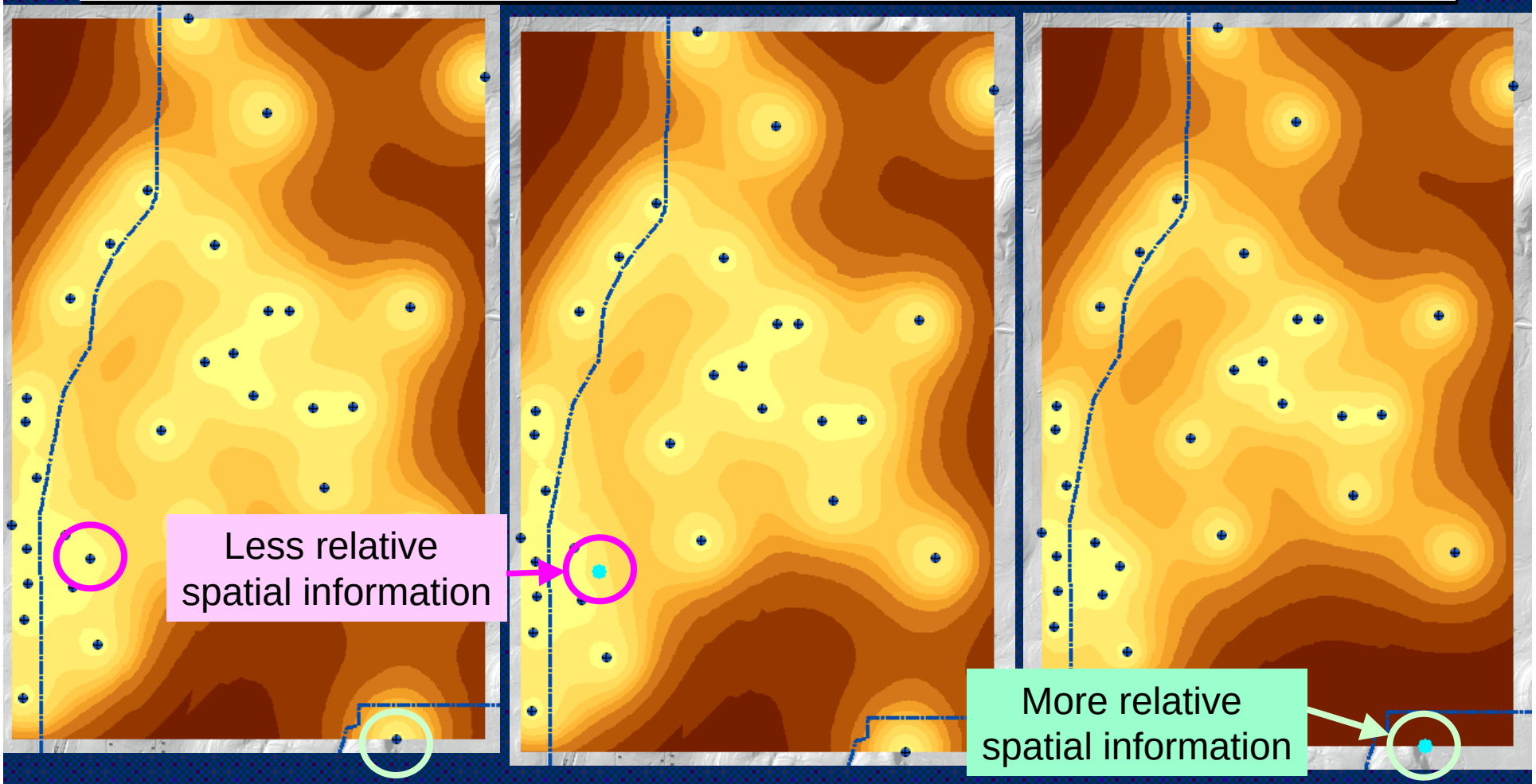
Idealized Semivariogram Model

"Best fit" curve

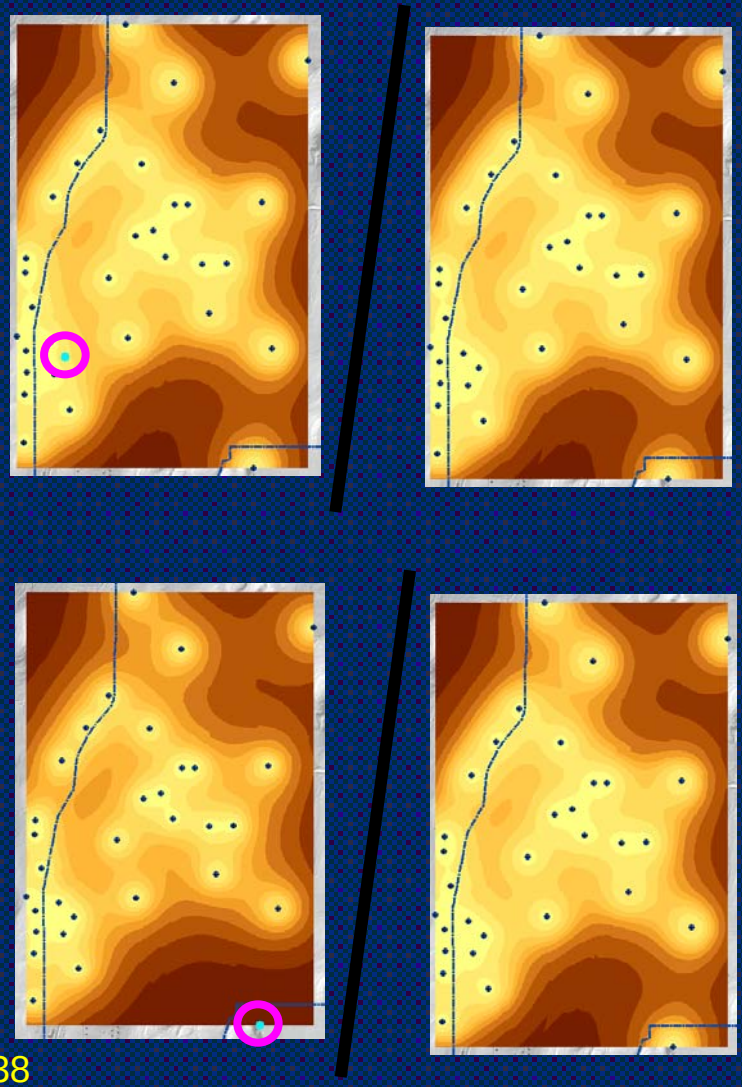


Case Study Semivariogram Model

Calculate Predicted Standard Error for Basecase & “Missing Well” Scenarios



Calculate Spatial Metrics for Each Well



Missing CS-10/Basecase = 1.001

$$\frac{\text{Median Missing Well Grid}}{\text{Median Basecase Grid}} = \text{Spatial Metric}$$

Missing CS-1/Basecase = 1.01

Case Study Wells: Spatial Evaluation

Well ID	Spatial Metric	Kriging Ranking	Remove/ Exclude	Retain/ Add
CS-4	0.99930	1	X	
CS-MW2-A	0.99956	2	X	
CS-MW1-A	0.99964	3		
CS-11	0.99986	4	X	
JW-13	0.99987	5	X	
JW-9	0.99988	6	X	
JW-14	0.99990	7	X	
JW-12	1.00000	8.5	X	
RFR-8	1.00000	8.5	X	
CS-9	1.00007	10	--	--
RFR-7	1.00008	11	--	--
CS-D	1.00011	12	--	--
CS-10	1.00067	13	--	--
RFR-6	1.00229	14	--	--
CS-MW16-A	1.00335	15	--	--
CS-2	1.00471	16	--	--
FO-22	1.00471	17	--	--
CS-I	1.00498	18	--	--
CS-1	1.00551	19	--	--
CS-MW5-A	1.00854	20	--	--
RFR-9	1.00868	21	--	--
CS-MW18-A	1.01150	22		X
CS-MW9-A	1.01706	23		X
CS-MWH-A	1.01766	24		
FO-8	1.01913	25		X
CS-MW12-A	1.02196	26		X
RFR-3	1.02197	27		X
CS-MW3-A	1.02380	28		X
CS-MW17-A	1.02402	29		X
CS-MW4-A	1.02595	30		X
CS-MW19-A	1.02990	31		X
CS-MWG-A	1.03843	32		X

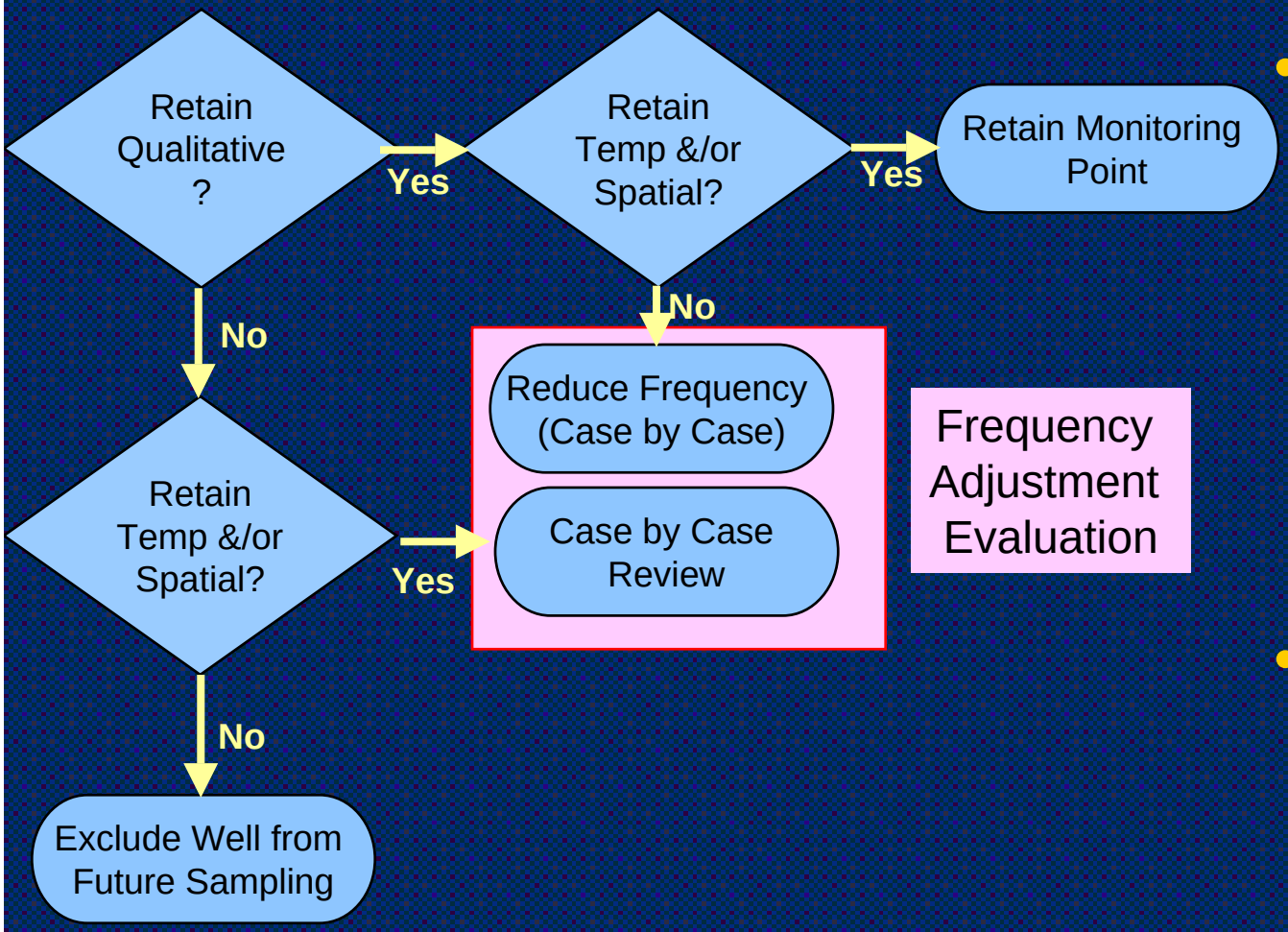
???

???

Based on Kriging Metric, Recommend remove, retain or no recommendation (intermediate range) for case study wells based on relative value of spatial information

See Table 8 and Handout for Spatial Results & Evaluation Template

Combined Evaluation Summary



- Combine 3 Analyses to Determine Final Distribution and Frequency Recommen-dation
- Qualitative Verified & Refined by Quantitative

Case Study Evaluation: Combined Evaluation Summary

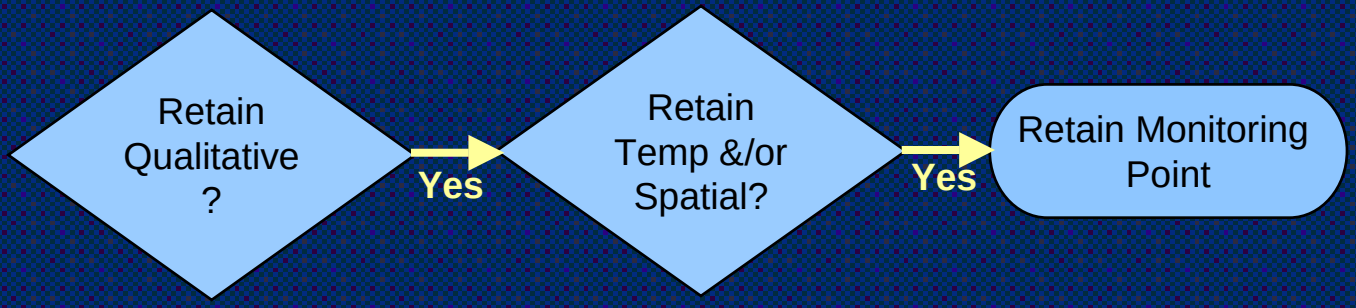
Well ID	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation		Summary			Rationale
		Remove	Retain	Frequency	Remove/ Reduce	Retain	Remove/ Reduce	Retain	Remove	Retain	Recommended Monitoring Frequency	
On Post Monitoring Wells												
CS-1	Quarterly		X	Semi-annual		X	--	--		X	Semi-Annual	Statistics confirm qualitative evaluation
CS-10	Quarterly		X	Semi-annual	X		--	--		X	Semi-Annual	Qualitative factor (water supply well) overrides statistic recommendations
CS-11	Quarterly		X	Annual	X		X			X	Biennial	Reduce frequency based on statistics
CS-2	Quarterly		X	Biennial	X		--	--		X	Biennial	Statistics confirm qualitative evaluation
CS-3	Quarterly	X		Remove	X		Not Included		X		Remove	Statistics confirm qualitative evaluation
CS-4	Quarterly	X		Remove		X	X			X		
CS-9	Quarterly		X	Semi-annual	X		--d/	--		X	S	
CS-D	Quarterly											
CS-I	Quarterly	X		Remove	X		--	--	X			
CS-MW12-C	Quarterly		X	Biennial	X		Not Included			X		
CS-MW12-B	Quarterly		X	Biennial	X		Not Included			X		
CS-MW12-A	Quarterly											
CS-MW16-B	Quarterly		X	Semi-annual		X	Not Included			X	S	
CS-MW16-A	Quarterly		X	Semi-annual		X	--	--		X	S	
CS-MW17-A	Quarterly		X	Annual	X			X		X		
CS-MW18-A	Quarterly		X	Annual	X	0		X		X		
CS-MW19-A	Quarterly		X	Annual	X			X		X		
CS-MW1-C	Quarterly		X	Biennial	X		Not Included			X	Biennial	Statistics confirm qualitative evaluation
CS-MW1-B	Quarterly		X	Biennial	X		Not Included			X	Biennial	Statistics confirm qualitative evaluation
CS-MW1-A	Quarterly											
CS-MW2-B	Quarterly		X	Biennial	X		Not Included			X	Biennial	Statistics confirm qualitative evaluation
CS-MW2-A	Quarterly		X	Biennial	X		X			X	Biennial	Statistics confirm qualitative evaluation
CS-MW3-A	Quarterly		X	Biennial	X			X		X	Biennial	Statistics confirm qualitative evaluation
CS-MW4-A	Quarterly	X		Remove	X			X		X	Biennial	Retain well due to spatial analysis
CS-MW5-A	Quarterly											onfirm qualitative evaluation

Formulate final recommendations for removal/retention and monitoring frequency based on qualitative, temporal, and spatial recommendations, and the Summary decision rationale

See Table 9 & Handout for Combined Results & Summary Template

CS-D Combined Summary

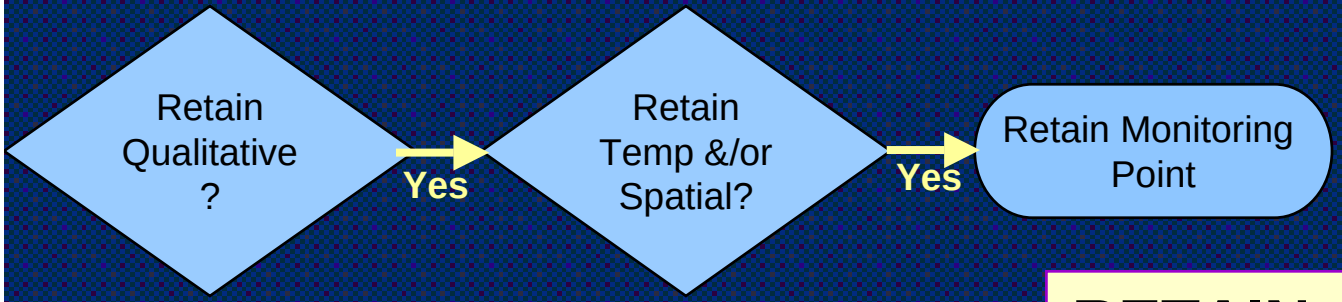
Well ID	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation	
		Remove	Retain	Frequency	Remove/ Reduce	Retain	Remove	Retain
CS-D	Quarterly		X	Semi-annual		X	--	--



RETAIN well @ Semi-Annual Sampling Frequency: Temporal statistics confirm qualitative evaluation

CS-MW12-A Combined Summary

Well ID	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation	
		Remove	Retain	Frequency	Remove/ Reduce	Retain	Remove	Retain
CS-MW12-A	Quarterly		X	Biennial	X			X



RETAIN well @ Biennial Sampling Frequency: Statistics confirm qualitative evaluation

CS-MW1-A Combined Summary

Well ID	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation	
		Remove	Retain	Frequency	Remove/ Reduce	Retain	Remove	Retain
CS-MW1-A	Quarterly		X	Annual		X	X	

CS-MWH-A Combined Summary

Well ID	Current Sampling Frequency	Qualitative Evaluation			Temporal Evaluation		Spatial Evaluation	
		Remove	Retain	Frequency	Remove/ Reduce	Retain	Remove	Retain
CS-MWH-A	Quarterly	X		Remove	X			X

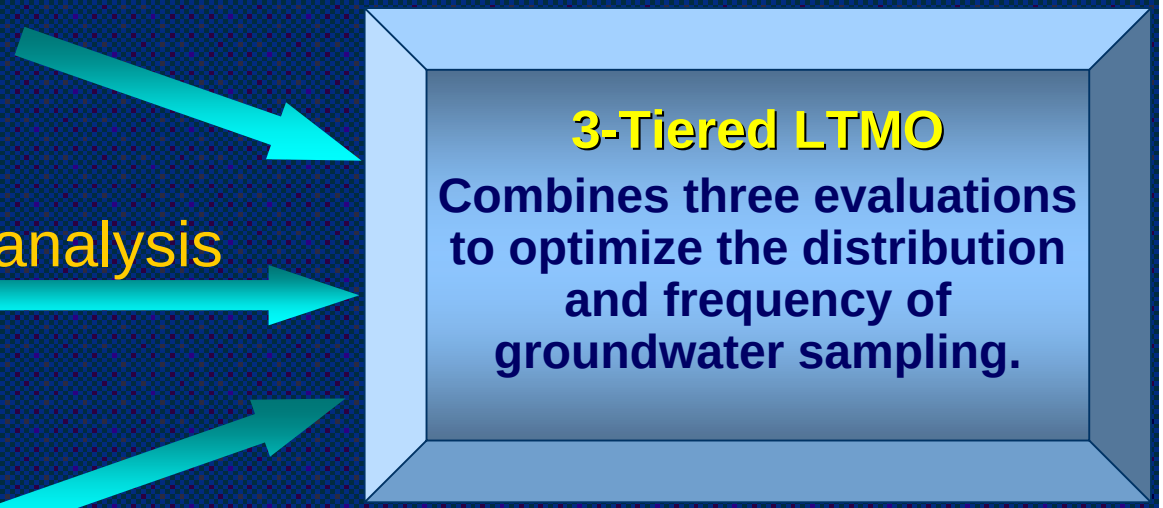
LTMO Case Study Results

	Original Network	Revised Network
Total Wells	41	35
Biennial	0	20
Annual	8	9
Semi-Annual	0	6
Quarterly	33	0
Total Sampling Events	140	31

77.9% Potential Monitoring Reductions in Sampling Events per Year

3-Tiered LTMO Summary

- Qualitative Evaluation
  - Experienced geologist big-picture analysis
- Temporal Statistical Evaluation
  - Mann Kendall trend analysis
  - Decision rationale
- Spatial Statistical Evaluation
  - Geostatisical Kriging relative predicted error analysis



Applications

- 20+ Sites in Past 3 Years
- 10 to 300+ Well Monitoring Networks
- Identified 13% - 83% Reductions*
- On Average Identified Over 1/3 Reductions*
- Results Highly Dependant on Site Conditions
  - No recent optimization and more frequent current sampling → higher identified reductions
  - Sites with small number of wells can still lead to significant relative reductions

*Reduction in average sampling events per year

Thank you!

PARSONS' 3-Tiered Approach to LTMO

For more information please contact:

Carolyn Nobel
Carolyn.Nobel@parsons.com
(303) 764-8866

John Hicks
John.Hicks@parsons.com
(303) 764-1941